Timing and Spectral Studies of Gamma Ray Burst (GRB) 080607 detected with Swift Mission

Moti R. Dugair, Sapna Sharma, K. P. Talesra, D. Bhattacharya and S.N.A. Jaaffrey

Abstract— We present timing and spectral studies of GRB080607 detected with SWIFT/BAT Mission. Using cross-correlation function (CCF) we established correlation between dependent variables like energy-flux, energy-lag, energy-luminosity and lag-luminosity. These dependent parameters between different energy bands in GRBs can be explained on the basis of continuous transformation of gravitational energy of collapsing matter into radiation emission during the formation of a collapsar. Both flux and luminosity increase rapidly for the energy bands (15-25 keV to 50-100 keV) but slow for the higher band, 100-150 keV. This may be attributed to convergence of bulk matter towards the core under its own gravity during implosion in collapsar. Under anti correlation, luminosity is higher for negative lagging photon & low for positive lagging photon because of the internal & external shocks in GRB. Nevertheless short and long GRBs exhibit this behavior ubiquitously and suggest that a similar process is responsible for producing all GRB pulses regardless of their environment and progenitor.

Index Terms— gamma rays: bursts: individual (080607): timing studies: cross correlations: energy-lag, energy-flux, energy-luminosity and lag-luminosity: spectral studies.

1 Introduction

Gamma ray bursts (GRBs) are highest luminosity flashes of gamma radiation of cosmic origin lasting from ten milliseconds to several minutes, whose energy degrades in its afterglow. GRBs were first observed in 1967 by satellites during the monitoring of the nuclear test ban treaty and are now being observed regularly for astronomical goals [4]. Our understanding about the most proposed explanations implicate cataclysmic events, but there is still no generally accepted mechanism for GRBs.

First time Norris [24] observed the spectral evolution of GRB pulses. The general diagnostics nature observed in GRB pulses that: pulse peaks widen at lower energies at later times and tend to soften at each individual evolving pulse. GRB studies provided attestation for two pulses in analysis of large BATSE burst samples [26], [25]. The cross-correlation analysis between four channel data revealed the trend of spectral softening on the time scale of pulses in an integral sense [3].

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However, Cheng [7] undermined cross correlation to demonstrate that soft emission had a time delay relative to high-energy emission. The spectral analysis of bright bursts and afterglow with the higher resolution confirmed the tendency of softening as they progress [11].

The origin of the pulse is probably more closely attributed to the primal energy generation rather than dissipation mechanism. Based upon the pulse anatomy, Norris [22] noticed that the rise-to-decay ratio is unity or less; as this ratio decreases, pulses tend to be wider, the pulse centroid is shifted to later times at lower energies, and pulses tend to be spectrally softer though the correlation of pulse spectral hardness with pulse symmetry was less clear. Moreover, the large number of studies has observed that pulse with in a given burst tends to exhibit little variation in pulse width. Later Fenimore, Ramirez-Ruiz [10] employed auto correlation analysis and concluded that different intervals with in GRB990123 exhibit comparable pulse widths.

The intrinsic parameter in GRB studies is the lag which is the delay between photons observed in high-energy band pass relative to a lower energy one; it is primarily obtained through application of the cross-correlation function (CCF; Band [3]). Norris [23], [21] believed that lag is a signature for both GRB peak luminosity and time history morphology with short-lag variable bursts having greater luminosities than long-lag, smooth bursts [14].

Often the extreme GRBs have been the most illuminating both literally and figuratively. The huge isotropic-equivalent energy of long duration GRB 971214 (redshift $z = 3.43$, $E_{iso} = 3 \times 10^{53}$ erg; Ramaprakash [31]; Odewahn [27]; Kulkarni [20] emphatically demonstrated the need for collimation to bring the energy budget of reasonable values. Under typical observations of the mag 9 optical flash of GRB 990123 (z = 1.61, E_{iso} = 3.4 × 10^{54} erg; Akerlof [2]; Kulkarni [19] precluded the utility of GRBs to probe the high-redshift universe: ideally it would be easily detectable even at z > 6. This opportunity was first reconciled by GRB 050904 (z = 6.29, E_{iso} = 1.2 × 10^{54} erg; Kawai [18]; Sugita [34], which for three years remained the most distant GRB known and, at the time, was also the most luminous optical transient observed in the universe [17]. The subsequent record has since been surpassed dramatically by GRB 080319B (z = 0.937, E_{iso} = 1.3 × 10^{54} erg), whose optical afterglow peaked at V ≈ 5 mag (Racusin [30]; Bloom [5]; Woźniak [35]). The remarkable current record for the enormous bolometric isotropic-equivalent energy is embraced by the Fermi burst GRB 080916C (Eiso = 6.5 × 10^{54} erg; Abdo [1]; Greiner [13]).

Joining this list of record setters is GRB 080607 (z = 3.036; Prochaska [29]), with E_{iso} = 1.87 × 10^{54} erg (Golenetskii [12]). This GRB is astounding not only for its generic properties, but also because of its unusual environment of cloud in host galaxy as detected by Prochaska [29]. A Keck-spectrum obtained proclaims 20 minutes after the burst reveals that the sight-line penetrates a giant molecular cloud in the host galaxy, obscuring the rest-frame visible light by AV ≈ 3 mag of extinction (or ∼6 mag at 1600 Å, corresponding to the observed R band) before it even traversed through intergalactic space. The small optical telescopes for over an hour were quite efficient to detect such bright GRB despite of its extreme attenuation.

GRB 080607 has endowed the first observational evidences of molecular absorption bands toward any galaxy hosting a GRB [33]. GRB 080607 had highly extinguished (AV ≈ 3 mag) afterglow yielding spectroscopic absorption line due to enough brightness [8]. Chen [9] discovered an error in the photometric measurements of the host galaxy in Spitzer IRAC images. The host galaxy was detected in the IRAC 3.5 μm and 4.5 μm channels with AB (3.5μ) = 22.9±0.2 and AB (4.5μ) = 22.7±0.2 mag.

2. OBSERVATIONS

The Burst Alert Telescope (BAT; Barthelmy [4]) on board the Swift satellite targeted GRB 080607 at 06:07:27 on 2008 June 7. The BAT on board the Swift measured location with an uncertainty of 1.0 arc min (radius, 3- sigma, including systematic uncertainty) is RA= 194.964; 12:59:51.4, Dec=15.910; 15:54:36.0. This is very bright burst, yielding about 1500 counts over background in 64 s in the 25-100 keV range in BAT instrument. This corresponds to a rate of 10 counts /sec/cm² in the 64 interval. A long bright GRB080607 triggered konus-wind at 176.704 s UT. Its redshift is Z=3.036 (Keck I). This is the third closest long GRB discovered by the Swift. VLT, Gemini and TNG telescopes were used to observe the afterglow.

Swift maneuvered immediately to the sight of GRB source and made successful pointed observations with the X-ray Telescope (XRT; Burrows [6]) at 82 s, followed by UVOT measurements with the Ultraviolet Optical Telescope (UVOT; Roming [32]) beginning at 100 s. Observations continued until 1049 s, after which Swift slewed away temporarily, returning to the field at 4226 s. From then, observations continued intermittently over the next four days, after which the X-ray flux was too faint for Swift to detect. In this paper used data were taken from Swift/BAT online services.

3. DATA REDUCTION AND ANALYSIS

We studied timing and spectral properties of GRB080607 detected with SWIFT/BAT Mission using Ubuntu OS and appropriate software (HEAsoft6.11). Data reduction was done with available SWIFT software package.
We used batbinevt v1.48; crosscor v1.0 (xronos 5.22) and GNUPLOT v4.4 patch level 2 for timing analysis. For spectral analysis we used XSPEC version 12.7, CALDB version 1.0.1., batmaskwtevt v1.22, batbinevt v1.48, batfftimage v1.20, batcelldetect v1.85, battblocks v1.18, battblocks v1.18 batphasyserr 1.6, batupdatephakw 1.4, batdrmgen v3.6. We found four different pulses for GRB080607.

Light curves with time bin size 64 ms (for GRB080607) were generated from BAT data for energy range 15-150 keV thereafter the light curves were extracted. We identified four distinct pulses separately in light curve for energy range 15-150 keV and then evolved four energy bands 15-25 keV, 25-50 keV, 50-100 keV and 100-150 keV from each pulse. Last three energy band light curves were cross correlated with first one and found lag (time delay) as described by Band [3]. Using CCF lag we could coordinate several parameters to establish relations between energy-flux, energy-lag, energy-luminosity and lag-luminosity because of the strong signal. From GRB080607 clear four pulses could be unambiguously extracted with consistent characteristics across all energy bands. With in the limit of uncertainty observed due to pulse overlap and moderate signal to noise ratio, it is usually difficult to fit many overlapping pulses., it appeared that every pulse was characterized by its own lag. Execution of the software for the analysis across four different intervals allowed us to address the question of evolution of CCF lag. The lag was measured by Gaussian fitting in the region near CCF Main peak. The Gaussian profile was modeled as:

$$I(t) = I_o \exp[-(t-t_0)^2 / 2\sigma^2]$$

Luminosity is obtained from the following relation

$$L = 4\pi d_L^2 F$$

Where F is flux and d_L is luminosity distance.
We calculated luminosity distance (d_L = 27.7932 Giga parsec) using standard cosmological model (H_0=65 km/sec/Mpc, omega_matter=0.3, omega_lambda=0.73) for GRB080607.

4 RESULTS:

4.1 TIMING ANALYSIS

Figure 1 and Figure 2 represent plots (with error bars) of the observed flux and luminosity for four peaks pulse 1 (black), pulse 2 (red), pulse 3 (green), pulse 4 (blue) of GRB080607 as function of mid point of energy bands 15-25, 25-50, 50-100 and 100-150 keV respectively. These plots have the following common features: (1) Both photon flux and luminosity of four bands of four peaks show increasing trends with ratios, 1:2:3:6, 1:3:6:5, 1:2:4:5, 1:2:4:3. These ratios are obtained by dividing each data of peak flux and peak luminosity (as given in column 5 & 7 of table 1) individually for all four pulses by their first data.

(2) Except first peak, last three peaks flux & luminosity do not rise in high energy bands (100-150 keV) but get almost saturated. Low energy bands (25-50 and 50-100 keV) in all four peaks flux and peak luminosity rise with double ratio.

(3) Variations among peaks flux and luminosity is minimum in the energy band (15-25 keV) and maximum for 50-100 keV where as for 25-50 keV and 100-150 keV, it is more or less same.

Table 1: Pulse properties of GRB080607

Pulse	Energy Band (keV)	Lag (sec)	Lag error (sec)	Peak Flux (erg/sec cm^2) * 10^{-9}	Peak Flux error (erg/sec cm^2) *10^{-9}	Peak luminosity (erg/sec) * 10^{51}	Peak luminosity error (erg/sec) *10^{51}
I	15-25	0.0	0.0	120.4573	49.8614	11.0866	4.5891
	25-50	-0.1514	-0.0869	218.6717	83.6062	20.1261	7.6949
	50-100	-0.0880	-0.0745	379.8173	107.3530	34.9577	9.8805
	100-150	-0.0192	-0.1383	725.5637	241.3798	66.7795	22.2161
II	15-25	0.0	0.0	202.6790	42.6587	18.6542	3.9262
	25-50	-0.1136	-0.0474	551.6785	74.6982	50.7202	6.8750
	50-100	-0.1289	-0.0448	1302.2169	157.5418	119.8537	14.4998
	100-150	-0.1944	-0.0699	1069.3312	261.0528	98.4193	24.0268
III	15-25	0.0	0.0	185.1814	47.0552	17.0437	4.3308
	25-50	-0.0181	0.0745	388.6954	66.7083	35.7743	6.1397
	50-100	-0.0476	0.0693	758.2251	133.3801	69.7856	12.2760
	100-150	-0.1877	-0.0620	902.5885	217.8584	83.0726	20.0513
IV	15-25	0.0	0.0	119.2218	32.4242	10.9729	2.9842
	25-50	0.1952	-0.079	240.4391	54.7870	22.1295	5.0425
	50-100	0.0691	-0.0632	427.1570	99.6935	39.3147	9.1756
	100-150	0.3291	-0.1130	353.5932	17.6686	32.5440	1.6261

These features reveal that as soon as GRB episode begins the photon flux and luminosity are more intense but at later succession time of burst gradually decline, which is in good agreement with earlier studies [16].

Figure 3 shows that lag of first pulse rises from -0.15 sec to -0.09 sec. It means high energy bands of 1st pulse (black) come before the low energy band. Compton scattering of the initial photons emitted in GRB episode by rare & anisotropic interstellar matter delays photons as compared to other which have escaped.

In figure 3 the gamma photons of in second pulse (red) do not show appreciable change in delay as a function of energy band which represent the throw of anisotropic interstellar matter in empty space by intense photon pressure.

Anti-correlation is exhibited by the gamma photons of 3rd pulse (green color, see figure 3) undergoing negative lag which declines from -0.09 sec to -0.2 sec. The 4th pulse (blue) in GRB demonstrates variability in lag as a function of energy band that slows that photons of 3rd pulse due to internal pressure stop most of the low energy photons under multiple scat tering but high energy photons escape because of the low scattering cross section. As indicated by Hakkila [16], the anti-correlation between luminosity and lag is ubiquitous in almost all observed GRBs.

Luminosity is higher for negative lagging photon & low for low for positive lagging photon (figure 4) because of the internal & external shocks in Gamma Ray Burst.

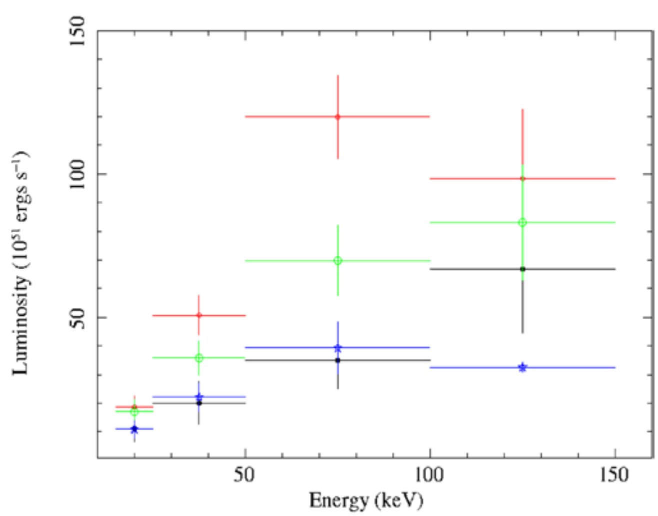

Figure: 1 Presents energy vs flux for 64 ms timing for four different pulses for GRB 080607

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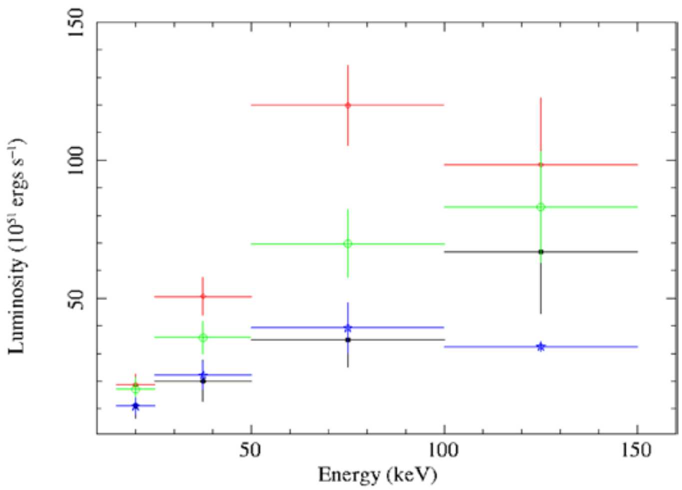


Figure: 2 Presents energy vs luminosity for 64 ms timing for four different pulses for GRB 080607

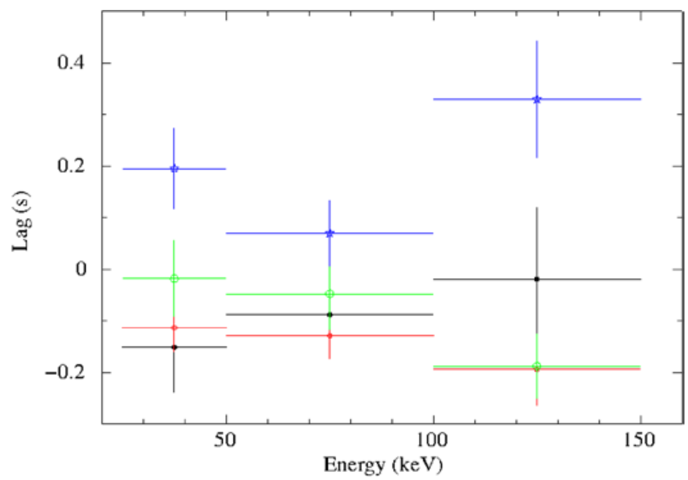
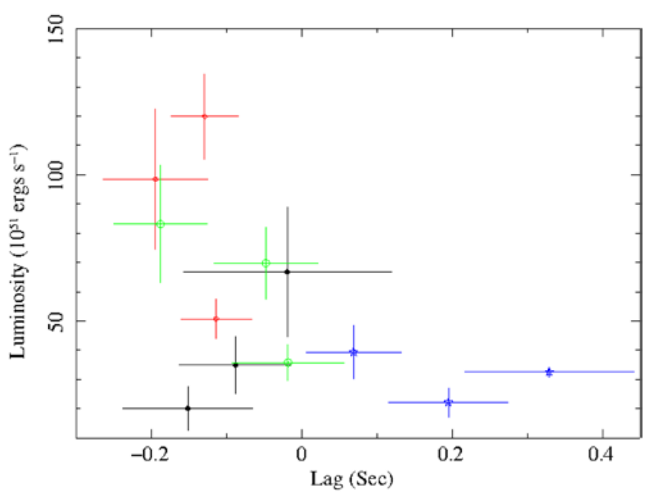


Figure: 3 Presents energy vs lag for 64 ms timing for four different pulses



for GRB 080607

Figure: 4 Presents lag vs luminosity for 64 ms timing for four different pulses for GRB 080607

4.2 SPECTRAL ANALYSIS

GRB080607 power spectrum is plotted as shown in figure 5. Spectrum shows quite simple power law model to be fitted. In the spectral power-law fitting we found photon index = 1.07 ± 0.076; power law normalization = 0.085 ± 0.028, reduced chi square = 0.7721 for 45 degrees of freedom for GRB080607. The residuals justify power law fitting as shown in lower panel. This spectral analysis of data simply indicates that origin of the power in the GRB is probably primal energy generation mechanism rather than dissipation.

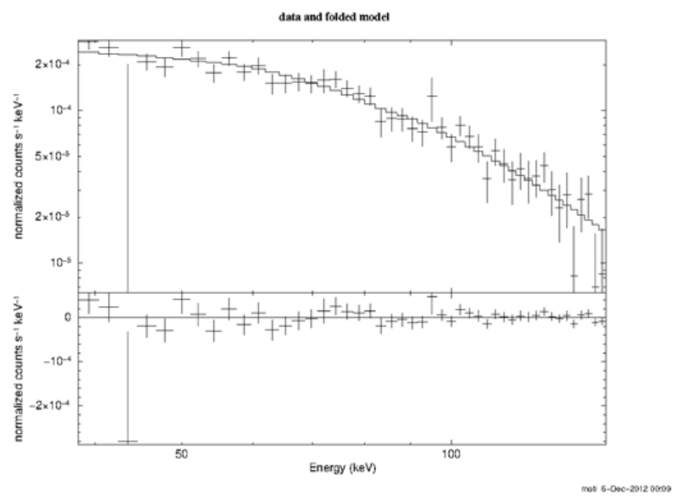


Figure: 5 Presents power law with residuals (spectral fitting) for GRB 080607

5 CONCLUSION

GRB 080607 is the brightest and best-studied among the Swift era GRBs. The observed photon flux, lag, redshift for GRB080607 hold particular potential to reveal the nature of GRBs and their environments [28]. GRB080607 represents a unique example of a dark GRB that was luminous enough to allow detailed observations of its afterglow despite it occurring in a heavily obscured galaxy [8].

GRB080607 exhibited the dependence of flux, luminosity and lag as a function of the different energy bands. The cross-correlation function (CCF) established correlation between energy-flux, energy-luminosity and anti-correlation between lag-luminosity, energy-lag variables. This is in good agreement with the results of Hakkila [15]. The lag between different energy bands in GRB could be explained on the basis of continuous transformation of gravitational energy of collapsing matter into radiation emission during the formation of a collapsar. The observed GRB peak of 80 sec duration, made a point to believe that GRB080607 is of long duration burst and the peripheral collapsing matter emitted low energy band as compared matter close to the core. The time delay between low energy and high energy bands (emitted from inner matter) would be large i.e. low band will reach early than the higher energy band. However extraction of distinguishable GRB pulses was difficult due to overlapping and low signal to noise ratio, but the measured properties of pulses and their intrinsic correlations & anti correlations are strong enough to not be diluted into insignificance by the dispersion in distances and redshift. Although our understanding about the most proposed explanations implicate cataclysmic events, but there is still no generally accepted mechanism for GRBs.

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